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THE EFFECT OF LINE-OF-SIGHT RATE TOLERANCE ON A PROPOSED BACKUP GUIDANCE TECHNIQUE FOR LEM-CSM RENDEZVOUS

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SUMMARY

A study of the effect of line-of-sight rate tolerance on a proposed backup guidance technique for LEM-CSM rendezvous is presented. Variation of the value of line-of-sight rate as a thrust-off criterion showed little effect on the ΔV performance or the ability to perform the rendezvous within the boundaries investigated. Thrust misalinement errors were also considered. The effect of these errors showed an increase in ΔV. However, the effect of the errors was very nearly independent of the line-of-sight rate value used for the thrust-off criterion.

INTRODUCTION

The Theoretical Mechanics Branch has been investigating terminal rendezvous techniques that can be utilized to monitor rendezvous controlled by the LEM Primary Navigation and Guidance System (PNGS) and to control rendezvous in the event of a PGNS failure. The study has brought out a promising technique which utilizes range, range-rate, and line-of-sight (LOS) rate information. The range and range-rate are used as a thrust-on criterion. The LOS-rate information is used as a thrust-off criterion. The purpose of this report is to present the results of an investigation of the effect of varying the value of LOS rate used as a thrust-off criterion.

BACKUP GUIDANCE TECHNIQUE

The proposed backup guidance technique for the LEM-CSM rendezvous is illustrated in figure 1. The plane of relative motion between the spacecrafts is defined by the LOS range and the LOS angular rate. Both of these quantities are inertial quantities with respect to a selenocentric reference frame. The guidance technique consists of two distinct thrust modes. Thrust 1 is applied along the LOS range in the plane of motion. Thrust 2 is applied normal to the LOS range also in the plane of motion. The function of thrust 1 is to reduce the relative range rate in order to dock the spacecrafts. It accomplishes this by thrusting at predetermined relative ranges until the range rate is reduced to a predetermined selected value. The braking schedule for thrust 1 is shown in the first two columns of figure 2. The first range or the beginning of the rendezvous problem for this study is 10 n.m. At this range the range rate is reduced to 90 fps by thrusting along the LOS; i.e., the LEM is oriented such that the thrust vector is coincident with the LOS range vector and in a direction to reduce the range rate. The thrust is terminated when the range rate is 90 fps.

The thrust direction is fixed inertially until thrust is terminated. When the selected range rate is reached it is recorded and continually monitored. If the range rate decreases by an amount equal to or greater than the value in the Δ range rate column a thrust 2 correction is made. The thrust is applied in the manner described in figure 1 until the LOS rate is reduced to the value shown in the LOS rate column. For this correction the LEM is oriented such that the thrust vector is normal to the LOS and in a direction to reduce the LOS rate. The thrust vector is inertially constant until thrust termination. The philosophy here is that a constant range rate indicates an intercept trajectory and any significant decrease in range rate indicates a miss trajectory. If a correction is applied until the LOS rate is nulled to a desired level, the trajectory can be corrected to an intercept. When thrust 2 is terminated range rate is again recorded and monitored with the same Δ range rate value until the next range in the range column is reached. Thus the two thrust modes are associated to the extent that between each relative range for mode 1 in the range column there are corresponding values for a Δ range rate and LOS rate for mode 2. Thus at 5 n.m. range the Δ range rate is changed to the associated value. This is stated in the column marked comments.

RESULTS AND DISCUSSION

The values shown in figure 2 were those used in the study for the thrusting criteria. The thrust levels used were 3500# for the first thrust of mode 1 and 200# for all others. Rendezvous was initiated at 10 n.m. relative range and terminated at a range of 500 ft with a range rate of 5 fps. The results are presented in figure 3.

The first trajectory is a 180° transfer perturbed to result in a 5-n.m. miss case. The LOS rate value for thrust cut-off was varied from .5 to 1.5 milliradians per second with no thrust bias error. After first increasing slightly, the ΔV consumed decreased as LOS rate was increased. When the thrust was biased the ΔV increased by a fixed amount until the LOS rate was increased to 1.5 milliradians per second. The thrust vector was biased for both mode 1 and mode 2 thrusting. The second trajectory is a 160°, 4.5-n.m. miss case. In this case the LOS rate was varied from .5 to 1.0 milliradians per second. With no bias errors a slight decrease in ΔV resulted with an increase in LOS rate. With a bias error of 7° magnitude an increase in ΔV for each LOS rate resulted. The same trends resulted for the third case which is a 160°, 6-n.m. miss trajectory. Trajectories with bias errors of $\pm 7^{\circ}$ were studied, but only the results of the worse cases were presented since the other cases required less ΔV than the zero bias cases. This is not unexpected since the orthogonal thrusting method is not optimum.

The fourth case studied is a 270°, 3.5-n.m. miss trajectory. This trajectory is representative of a very large velocity error introduced at a range of 25 n.m. before intercept. It can be seen that while the ΔV decreased as the LOS rate increased, the rendezvous could not be performed with a LOS rate of 1.0 milliradians per second. With this LOS rate a 3-n.m. miss case resulted.

CONCLUSIONS

The effect of LOS rate variation for thrust termination in terminal rendezvous has been studied. The results show that in most cases an LOS rate of 1.0 milliradians per seconds is tolerable. It has been shown also that the ΔV decreases as the LOS rate is increased. However, as the rendezvous conditions become more severe this tolerance must be lowered in order to perform the rendezvous.

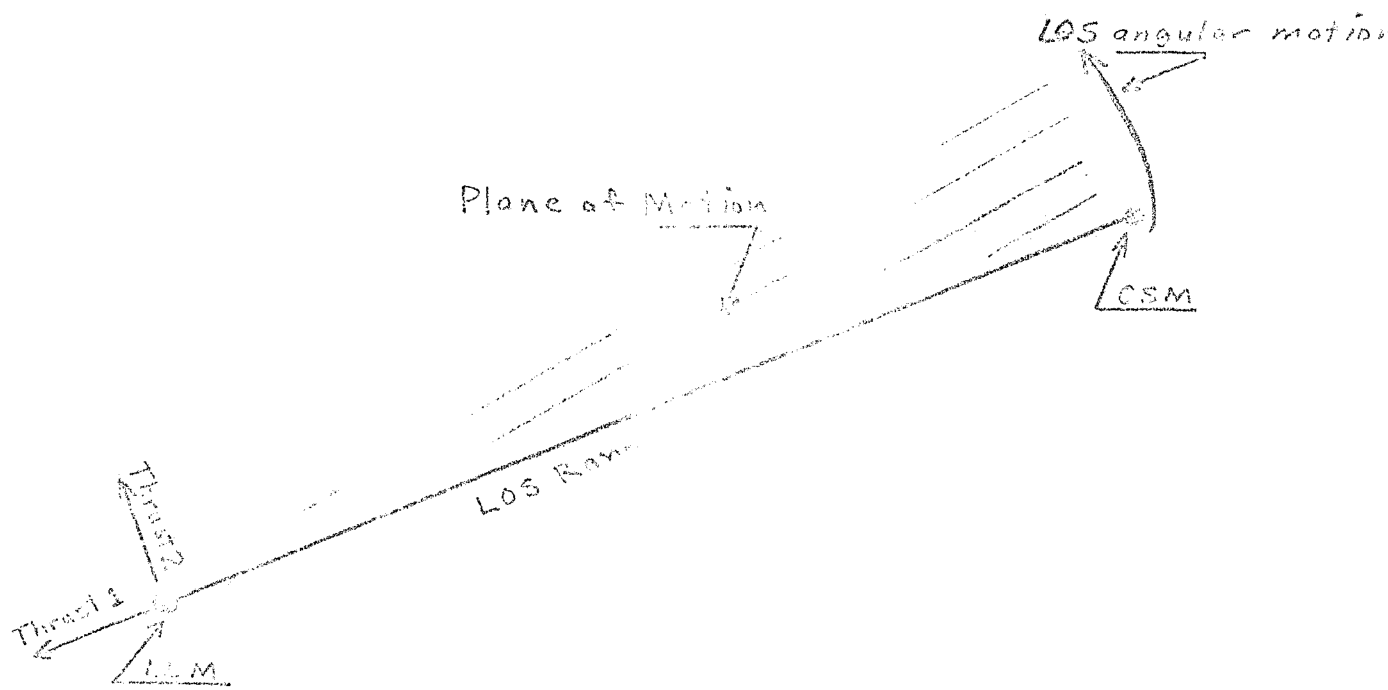

Figure 1 Direction of Thrust 1 and Thrust 2

Mode 1		Mode 2		Comments
Thrust on	Thrust off	Thrust on	Thrust off	
Range	Range Rate	Δ Range Rate	LOSR	Δ Range Rate value for Mode 2 Thrust, is 7.5 fps between 10 and 5 N.M, then it is 5 between 5 and 2 NM, etc.
10 N.M	90 fps	7.5 fps	1 $\frac{MR}{sec}$	
5 N.M	60 fps	5 fps	" "	LOSR was varied from .5 to 1.5 $\frac{MR}{sec}$.
2 N.M	30 fps	2 fps	" "	
.2 N.M	10 fps	1 fps	" "	
500 ft	5 fps			

Figure 2 Schedules for Mode 1 and Mode 2 Thrusting

Trajectory	LOS rate Tolerance, milliradians / second	Thrust Bias Error, degrees	ΔV, fps
180° ; 5 N.M Miss	.5	0	181
" " "	1.0	0	185
" " "	1.5	0	186
" " "	.5	7	193
" " "	1.0	7	192
" " "	1.5	7	189
160° ; 4.5 N.M Miss	.5	0	276
" " "	1.0	0	273
" " "	.5	7	291
" " "	1.0	7	295
160° ; 6 N.M Miss	.5	0	268
" " "	1.0	0	260
" " "	.5	7	280
" " "	1.0	7	266
270° ; 3.5 N.M Miss	.5	0	408
" " "	.75	0	420
" " "	1.0	0	3 N.M. Miss

Figure 3 Results of LOS rate Variation